Realisation and Validation of Servo Control System for Ship Borne Terminal (SBT)

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***Abstract*—ISRO's Telemetry Tracking and Command Network provides TTC (Telemetry, Tracking and Control) support for Launch Vehicles and Spacecrafts for all ISRO missions. BARC (Bhabha atomic research center, Mumbai), ECIL (Electronic Corporation of India limited, Hyderabad) and ISTARC (ISRO Telemetry and Command Network, Bangalore) have developed indigenous ship borne antenna terminal (SBT) to support ISRO missions which also include tracking of reentry vehicles for future Indian manned missions to space. SBT is a multirole three axis TTC terminal which is ship worthy and can be deployed on a ship deck where the ship can be positioned in high seas thus extending TTC support capability even in the remote areas. This 4.6m ship-borne terminal is capable of continuously pointing at the commanded angles and mono-pulse tracking even in the presence of ship's rocking movements. The antenna is actively stabilized against ship movements by the use of an Inertial Measurement Unit (IMU). A stabilization and tracking control system for a ship borne terminal have been developed to drive the antenna in Azimuth, Elevation and Cross Elevation planes. BARC is responsible for the development of three axis gimbals, controller electronics, motor drives, interlocks for the SBT and acceptance testing of the integrated system on Ship deck. This paper describes the realization and validation of stabilization and tracking control system for SBT.**

Keywords— SBT; TTC; 4.6m; BARC; ECIL; ISTRAC.

I. INTRODUCTION

The Ship Borne Terminal is a 4.6M diameter parabolic dish with the tracking accuracy of 0.2 deg. The SBT will have 'S' band transmit and receive capability. The overall height of the SBT is about 8.72 meters in deployed condition and weight is 5.4Tons as shown in fig.1.

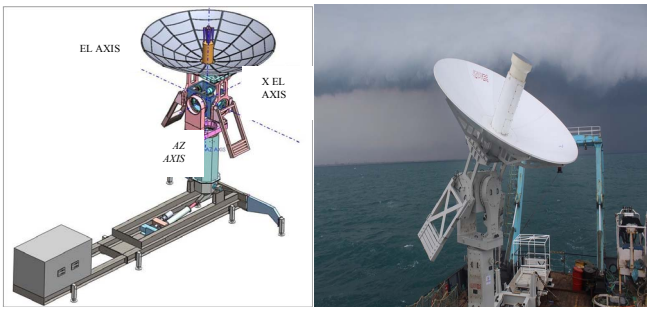

Fig.1. Three axis pedestal for SBT

The mount is of EL/ XEL over AZ type. The servo system is required to steer the Antenna in Azimuth (±380º), Cross EL (±27º) and Elevation (-27 to 123º) and support positioning of the dish and tracking of sources to 0.2 deg accuracy, at 60 KMPH wind speeds. The drive system must also support quick repositioning of the antenna to any position while switching from one source to another. Other requirements for the servo system include stowing under heavy wind or high sea states, hardware/ software travel limits, a local mode user interface, support for remote controlled operations etc.

II. SYSTEM SPECIFICATION

Major specifications are as follows-

TABLE 1 : SERVO PERFORMANCE SPECIFICATIONS

Parameter	*Value*
Angle Coverage in AZ	±380°
Angle Coverage in EL	-27° to 123°
Angle Coverage in XEL	±27°
Tracking speed (AZ, EL & XEL)	20°/sec
Angular acceleration	20°/sec2
Pointing accuracy	0.2°
Position sensor resolution	19 bit (better than 0.01)
Operational wind speed	60km/hr
Position loop BW	Better than 2 Hz
Stabilisation range	25°
Stabilisation rate	8°/sec
Stowing wind speed	> 60km/hr

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III. System Specification

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Position sensor resolution	19 bit (better than 0.01)
Operational wind speed	60km/hr
Position loop BW	Better than 2 Hz
Stabilisation range	25°
Stabilisation rate	8°/sec
Stowing wind speed	> 60km/hr
Survival wind speed	170km/hr
Operating Temperature	-40 to +80deg
Operating Humidity	100% (sea environment, saline)
Vibration	1.5g

IV. Basic Components of Stabilisation And Tracking Servo Controller

A stabilization and tracking system for a ship borne terminal to drive the antenna in Azimuth, Elevation and Cross Elevation planes have been realized. The major components are as follows-

A. Antenna Control Servo System (ACSS)

ACSS has all the salient features of modern digital control system available, using the state of art technology. The ACSS system consists of-

1. Antenna Control Unit (ACU)
2. Antenna Drive Unit (ADU)
3. ACU Remote Console(RC)

Fig.2. Antenna Control & Drive Unit Cabinet

The main servo controller functionality is built in the ACU. This system is a CPCI chassis containing custom made interface cards to support motion control devices and protocols.

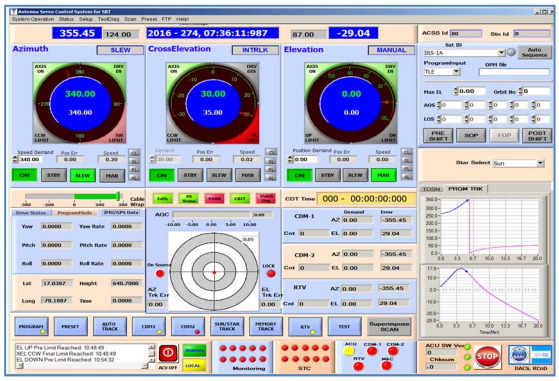

Fig.3. SBT HMI on Remote Computer

Remote Computer is the front-end for ACU and provides a gateway for all interfaces of ACU with user and other systems. The salient functions to be supported by the servo system are:

- Simultaneous positioning of the Antenna in AZ, XEL and EL at demand angles, within specified accuracy, speed and transient performance.
- Holding the Antenna at the demand angles in the presence of wind and other disturbances.

- Tracking of the target as per supplied target trajectory. It should provide an Ethernet/ TCP interface to external Remote Computer for this program.
- Measure the AZ/ XEL/ EL angles within stated accuracy from axis mounted encoders.
- Support parking/stowing operation of the Antenna
- Hardware / software travel limits
- Emergency stop
- Adequate man/ machine interface for monitoring and controlling the operation of the Antenna in both local and remote mode of operation.

B. Controller Architecture

The controller of the stabilization and tracking system implements three cascaded control loops, viz., current loop, speed loop, and position loop to track the target as shown in fig 4.

- All the three axes AZ, EL and XEL are driven by two BLAC motors each in counter torque arrangement. Each motor is driven using a 4-quadrant flux vector drive, which implements the torque loop. Torque demands are generated by ACU and sent to drives on CAN bus. Each motor / amplifier has its own current controller – hence there are two current loops per axis.
- Current loop is the inner most loop and is implemented in the Servo Star motor amplifier. The motor torque is proportional to the current and hence the purpose of current loop is to provide a constant torque drive.
- The speed loop encloses the current loops. The speed loop inside the position loop improves system damping. A high gain/ high bandwidth speed loop is desirable from the point of view of attenuating effect of torque disturbances, before these are sensed as significant position errors by the enclosing position loop. There is a single speed loop per axis.

- The ultimate performance of the servo is decided by the position loop controller. It encloses the speed loop with its output forming speed demand. The position error is computed as the difference between commanded position and measured position.
- The position feed-back is taken from the encoder. The position error (demand position - actual position) is filtered through a position loop compensator (PI), which implements Type-II servo. Type-II ensures zero position offset for ramp inputs and a constant offset for acceleration (parabolic) inputs.

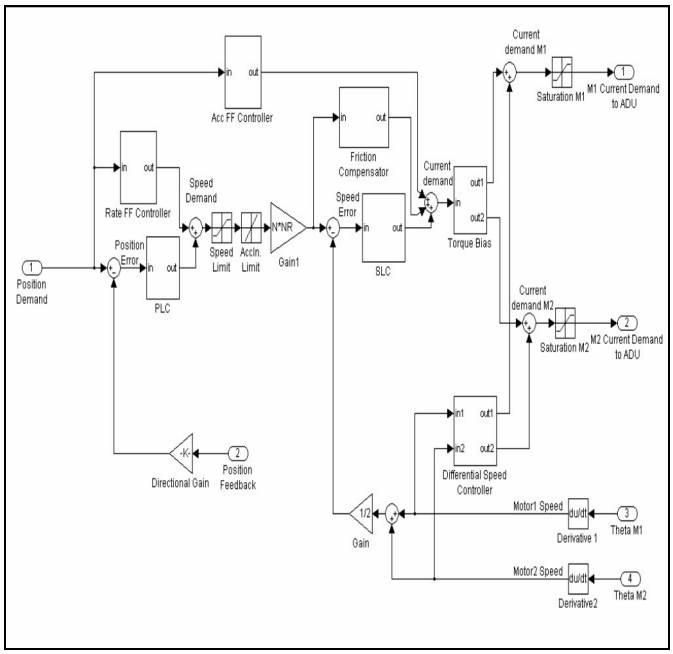

Fig.4. Overall ACS Controller Architecture

- Feed-forward controller, torque bias scheme, differential speed compensator etc. are also implemented in the controller to improve the servo performance of the system.

C. Stabilisation Unit

The system is required to facilitate the acquisition and auto-tracking of Launch Vehicles and Spacecrafts with the tracking accuracy of 0.2 deg even in the presence of ship's rocking movements or ship body attitudes (yaw, pitch and roll).
Since the 4.6M terminal is mounted on a ship for its operations, the servo control system compensates for the ship movements (attitudes), so that antenna looks at the target in designate or program modes of operations. These attitudes are obtained from the ship's navigation IMU (Inertial Measurement Unit mounted on the SBT.

V. ACCEPTANCE TESTING

In order to validate the system in stages the detailed factory acceptance testing (FAT) and on site acceptance testing (SAT) have been performed. Integral testing of the system is done in phased manner as given below-

A. FAT-Level-1

In this phase the antenna system is integrated with servo controls for all the three axes. The antenna servo and mechanical performance in all the three axes is verified to the specifications under simulated disturbances using Test Computer as shown in fig.5.

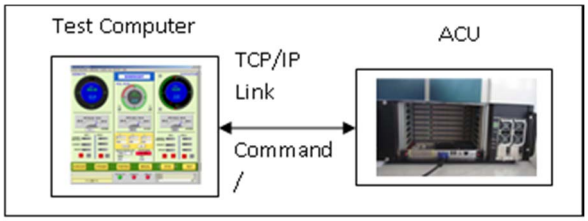

Fig.5. Test setup for FAT Level-I testing

B. *FAT-Level-2*

Level-II factory testing is performed with the RF subsystems. RF subsystem has been integrated to antenna along with servo controls for all the three axes.

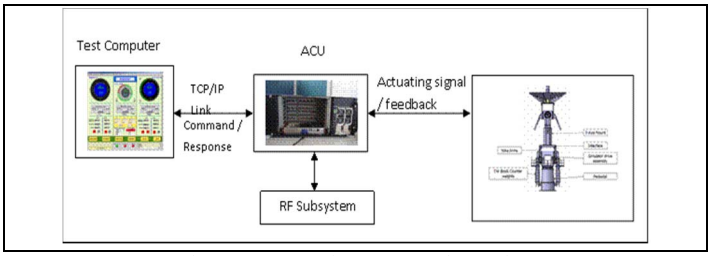

Fig.6. Test setup for FAT Level-2 testing

In order to verify the stabilization functionality of the three axis antenna mount a simulator is being designed in order to generate the ship motions as shown in fig.7.

Fig.7. Single axis Ship Motion Simulator

The 3-Axis mount is anchored on the simulator and the simulator is operated at velocity of 8º/sec , acceleration 10º/sec^{2}with a movement of ± 20 deg in single axis of the mean position (i.e., about Elevation axis) for generating the ship disturbance as shown in fig.8.

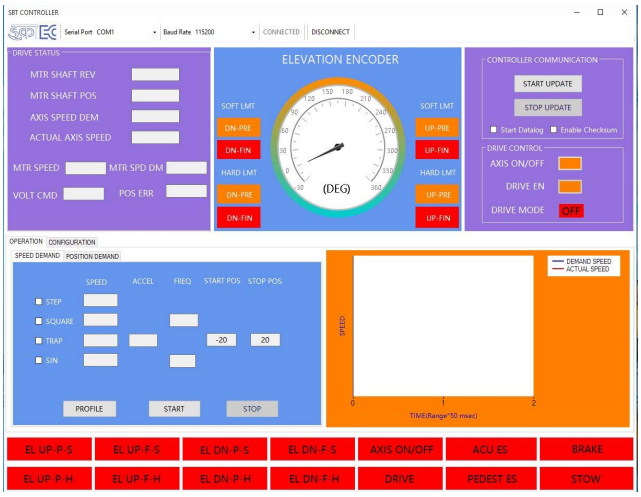

Fig.8. Ship Motion Simulator GUI

C. *SAT*

Site acceptance testing is performed with the fully integrated system for satisfactory performance before final delivery to ISTRAC. The antenna performance with RF subsystem has been verified to the specifications under the actual scenario. These tests are carried out on ship as described in next section.

VI. PERFORMANCE AND REALISATION

A. *Deployment*

ECIL has supplied indigenously built 4.6m Ship borne terminal to ISTRAC, ISRO in March 2017. ECIL played a vital role in deployment of the SBT on the trial ship. The deployment activity includes lashing of the SBT trailer on the ship, Reflector Panel Assembly, control wiring connectorization between Equipment Rack and SBT on deck as shown in figure 9.

Fig.9. SBT Deployment on ship

B. *SatelliteTracking*

The final test and validation of the antenna system have been done by tracking a launch vehicle in the mid sea.

Ship was moved in sea up to 100 Nautical Miles towards South-East and On 23rd June, morning 09.30 AM 4.6M SBT System successfully tracked the PSLV C-38 launch vehicle in S-band auto tracking.

Fig.10. PSLV C-38 launch vehicle tracking by SBT

C. Servo Performance during satellite tracking

4.6M SBT System successfully tracked the PSLV C-38 launch vehicle. During Auto tracking Max position error of 0.12^0 was observed with Max Az velocity demand of 6.5^0/sec and acceleration demand of $6^0/sec^2$ (for target and compensation demand). Maximum Roll of 8.7^0 at the peak rate 3.9 ^{0}/sec. Maximum Pitch of 3.2^0 at peak rate of 3.3^0/sec. Yaw maintained between 270^0 to 276^0. Servo plots showing antenna angles, body attitudes (Heading, Pitch, Roll), auto track errors, AZ speed, body rates are shown in following figures.

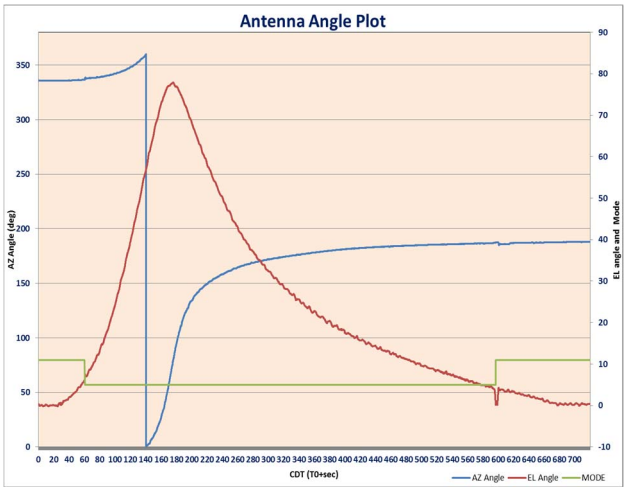

Fig. 11. Servo Plots – Antenna angle

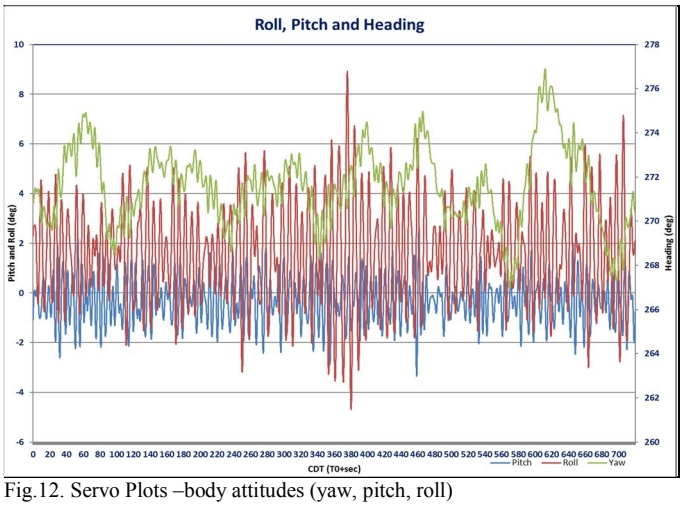

Fig.12. Servo Plots –body attitudes (yaw, pitch, roll)

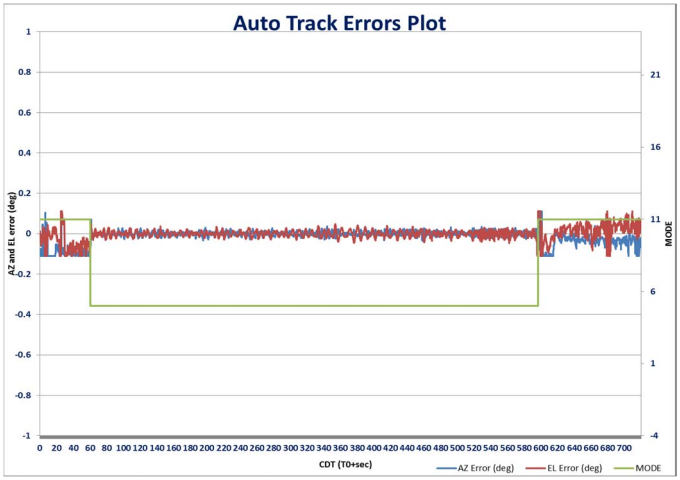

Fig.13. Servo Plots –Auto track errors

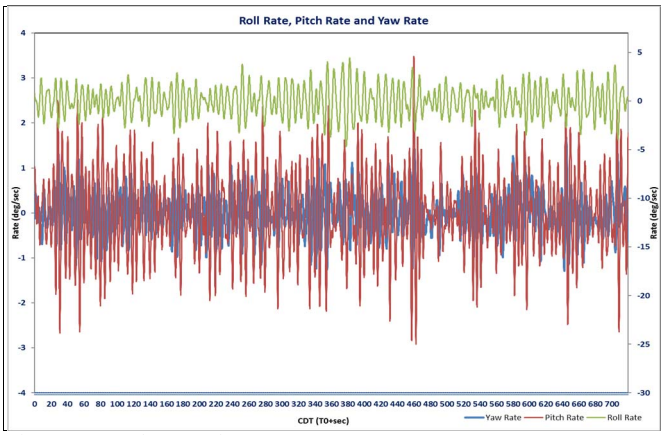

Fig.14. Servo Plots –Body rates

VII. CONCLUSION

Indigenous ship borne antenna terminal (SBT) developed by ECIL and BARC has cleared all the acceptance tests successfully and ready for deployment on ship for tracking Launch Vehicles, Spacecrafts and reentry vehicles for future Indian manned missions to space of ISRO.

ACKNOWLEDGMENT

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